PROCEEDINGS OF
INTERNATIONAL CONFERENCE ON ADVANCED TECHNOLOGIES
https://proceedings.icatsconf.org/
11th International Conference on Advanced Technologies (ICAT'23), Istanbul-Turkiye, August 17-19, 2023.

Analysis of Thermal Performance of Double Flow Finned Absorber Solar Air Heater

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***Abstract*— This paper investigated the thermal performance of a solar air collector with attached rectangular fins both theoretically and experimentally. The effects of mass flow rate (0.015 kg/s to 0.06 kg/s) and fin spacing on thermal performance and temperature rise were investigated using varying solar radiation intensity (500, 600, 700, and 800 W/m^2). The results show that, when using a finned absorber instead of a plane absorber, the maximum thermal efficiency of 1.264 times was achieved. Additionally, at a lower mass flow rate of 0.015 kg/s, a maximum increase in temperature rise has been observed to be 1.243 times greater than that of a plane absorber.**

***Keywords*— Solar Air Collector, Rectangular Fins, Mass Flow Rate, Thermal Efficiency, Temperature Rise**

I. Introduction

Energy use is increasing tremendously. The need for energy cannot be fulfilled for an extended period of time by conventional energy sources. Renewable energy sources are alternative energy sources that can meet demand. Solar energy is the most abundant, clean, and sustainable form of renewable energy. Flat plate solar collectors are the most commonly utilized solar thermal collectors due to their versatile applications and straightforward design. Solar collectors with flat plates for heating air are frequently used in homes, industrial, and agricultural fields.

Jalal M. Jalil researched absorbers using double-pass solar air heaters and wavy fins. When the findings of wavy-finned absorbers are compared to those of a plane, the increase in thermal efficiency for 3 and 7 wavy-finned absorbers, respectively, was 80% and 84% [2]. Som Nath Saha presented the mathematical model for the double-flow flat plate and various v-corrugated absorber angles. At 0.045 kg/s of air mass flow rate, the most efficient 60° corrugated absorbers double flow solar air heater obtains its maximum thermohydraulic efficiency [3]. Wavy fins significantly improve thermal efficiency by 1.29 times and temperature rise by 1.25 times as compared to longitudinal fins at a lower mass flow rate of 0.0134kg/s [4]. El. Sebaii compared outlet air temperatures, absorber temperatures, and output power of solar air heaters with double pass-finned and v-corrugated plates. Research shows double pass v-corrugated plate solar air heaters are 9.3-11.9% more effective [5]. The impacting air jets solar air heater enclosed by fins in the bottom of the absorber region for non-cross flow design has been the subject of an experimental investigation for various configurations [6]. According to a review of the literature and comparison research, solar air thermal collectors with fins transmit heat more quickly than those without fins [7]. N. F. Hussein investigated the thermal efficiency of two counterflow double-pass solar air heater configurations: conventional flat plate absorbers and water-filled tubular capsules. Due to the thermal storage substance, tubular capsules considerably increase the useful energy production of heaters and lengthen their lifespan [8]. Basim A. R. AL-Bakri examined the thermal efficiency of single-pass, double-pass, and triple-pass solar air heaters with pin fins. Triple-pass solar air heaters have 4 percent higher thermal efficiency than double-pass, while single-pass heaters have 7 percent lower efficiency [9]. Manish Sharma has investigated the thermal efficiency of a solar air heater with and without a gap-filled V-rib, and a plain observer plate for different mass flow rates. V rib solar air heater achieves 78% maximum thermal efficiency, 27.81%, and 37.27% higher than V continuous rib and without rib [10]. Offset fins with periodic interruptions are added to solar collectors. Soldering offset rectangular fins on absorber plates results in high thermal performance and lower electrical power consumption [11].

In this work, a solar air heater with rectangular fins attached to the absorber will be the subject of theoretical and experimental inquiry at various air flow rates. Examining mass flow rate, solar radiation intensity, and fin arrangement will be conducted to compare the performance of plane absorbers to finned absorbers.

II. Material and Method

A. Theoretical Calculation

The thermal effectiveness of the solar collector heaters will be examined. There are various parameters that must be determined in order to determine efficiency, such as the temperature difference between the input and exhaust air. Additionally, the efficiency is influenced by the features of the air and the intensity of the solar radiation.

Calculating the total heat gain is as follows:

$$Q_u = \dot{m}C_p(T_{out} - T_{in}) \quad (1)$$

$$\dot{m} = \rho uA \quad (2)$$

Hydraulic diameter calculation:

$$D_h = \frac{4A}{p} \quad (3)$$

Reynolds number calculation:

$$R_e = \frac{\dot{m}D_h}{A\mu} \quad (4)$$

The overall thermal efficiency of the solar heater will be evaluated

$$\eta_{th} = \frac{Q_u}{IA_c} \quad (5)$$

Where,

$\dot{m}$ is the mass flow rate of air (kg/s)

C_p is the specific heat of the air (kJ/kg.K)

T_{in} and T_{out} are the inlet and outlet air temperatures (K)

ρ is the density of the air (kg/m³)

u is the velocity of the air (m/s)

A is the area of the upper flow channel (m²)

I is the intensity of solar radiation (W/m²)

A_c is the area of the solar collector (m²)

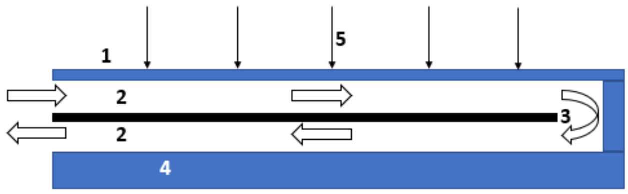
µ is the dynamic viscosity of the air (m²/s)

B. Experimental Set-Up

These models serve as a justification for the optimal design of these systems by indicating the thermal performance of double-pass solar air heaters. A schematic diagram of the double-pass solar air heater is shown in Fig. 1. The experimental setup was used to calculate the mass flow rate and flat plate air heater efficiency under various circumstances. The bases and sides of the collectors are made of plywood with a thickness of 12.7 mm. The layout of the solar air collector examined is depicted in Fig. 2. With the following parameters, the collector acted as the baseline:

- The collectors had dimensions of 1.22 m in length, 0.91 m in breadth, and 0.12 m in height;
- The collector was installed at a 45-degree inclination from horizontal;
- The translucent cover was made of glass, with a 3 mm thickness;
- The absorber plate was 2mm thick, painted black, and made of aluminum;
- The absorber had a coefficient of plate absorption of 0.95, a transmittance of the transparent cover of 0.9, and absorption of glass covers of 0.05;

On the base of the collector, a thermal insulation board (foam) with a thermal conductivity of 0.035 W/(mK) and a thickness of 12.7mm was laid. The experiments were conducted outside with 600, 700, 800, and 900 W/m^2 constant heat flux.



(1) Glass cover
(2) Airflow channel
(3) Absorber plate
(4) Insulation
(5) Solar radiation

Fig. 1 Schematic diagram of a double-pass solar air collector

By using an absorber plate, the collector is evenly divided into two channels, upper and lower. To induce air to shift its path from the top channel to the lower channel and exit the collector, an absorber plate was installed at a distance of 4.33 cm from the collector base, and an empty zone was produced with a length of 18 cm. As a result, it is known as a double-pass solar air collector. Both the input and output pipes on the collector include pipes with a diameter of 43mm. With the aid of a 12V, 0.24A fan, the system was supplied with air. The Arduino board is used to program and control the fan, which regulates the airflow rates. Several airflow rates between 0.015kg/s and 0.06 kg/s were used in the experiments. In the experiment, the intake, outflow, and absorber plate temperatures were measured using eight thermocouples. With an anemometer, air velocity is measured. Using a solar meter, the intensity of the solar is measured. The absorber plate is adorned with 18 fins, each measuring 16 cm in length, 3 cm in breadth, and 2 mm in thickness. The space between adjacent fins is 20 cm for the collector's length and 8.3 cm for its width. The physical and thermal properties of the various engineering materials used in the experiment are shown in Table I.

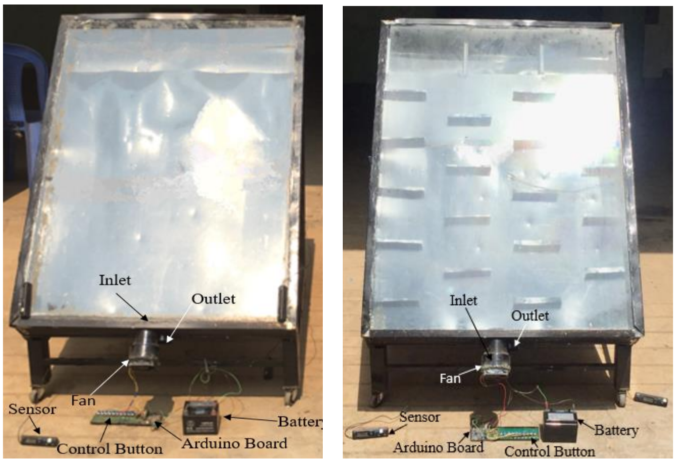


Fig. 2 Experimental setup of double-pass solar air collector integrated without fins and with fins absorbing surfaces

TABLE I
PROPERTIES OF THE MATERIALS

Material	Density (kg/m^3)	Specific heat capacity (J/kgK)	Thermal conductivity (W/mK)
Aluminium plate (Absorber)	2710	900	238
Glass (Cover)	2500	840	1.4
Foam (Insulation)	23	1131	0.035
Air	1.059	1007	0.02808

III. RESULTS AND DISCUSSION

The various graphs representing the experimental data and calculated terms are described in this section. Comparisons between the plane absorber and the finned absorber have been made for various solar radiation intensities and varied mass flow rates. Theoretically, Figures 3 and 4 depict the variation in air temperature rise for plane and finned absorber solar air heaters with various mass flow rates.

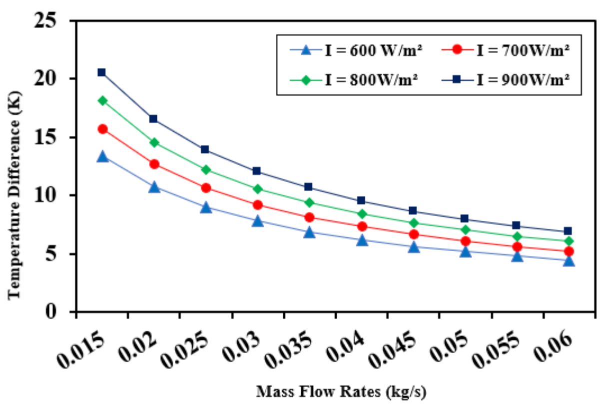


Fig. 3 Temperature differential variation with respect to mass flow rate for various solar radiations (Plane Absorber, Theoretical)

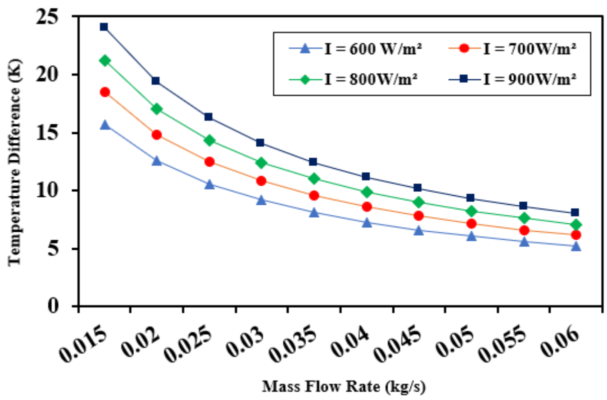


Fig. 4 Temperature differential variation with respect to mass flow rate for various solar radiations (Finned Absorber, Theoretical)

Figures 5 and 6 for varying solar radiation in the experiment indicate the impact of mass flow rate on the temperature differential between input and output air temperatures for the plane and finned absorber. The temperature differential decreased where the mass flow rate increased because more heat may be distributed from the absorber to the airflow at low speeds. The highest temperature differential in a finned absorber solar air collector is 22.887 K at an air mass flow rate of 0.015 kg/s because the fin will disturb the boundary layer, allowing for more heat transfer between the absorber and airflow. The temperature differential increases as solar radiation intensity rises because black bodies absorb solar energy and transform it into heat, raising the temperature of the absorber plate in the process. The reason for the greatest temperature difference in a finned absorber solar air collector, which is 900 W/m^2, is that the fins prolong the absorbing area, creating a larger area for solar radiation absorption and for convectional heat transfer between the absorber and airflow.

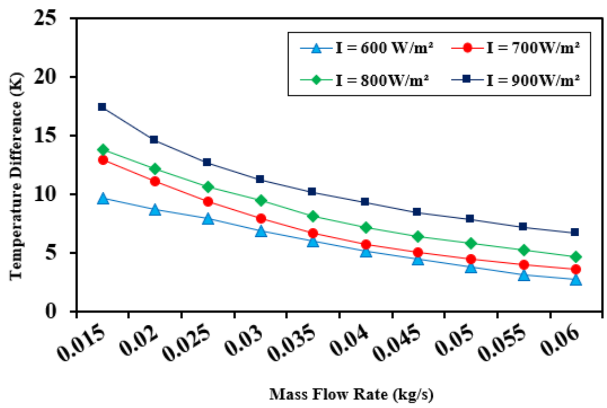


Fig. 5 Temperature differential variation with respect to mass flow rate for various solar radiations (Plane Absorber, Experimental)

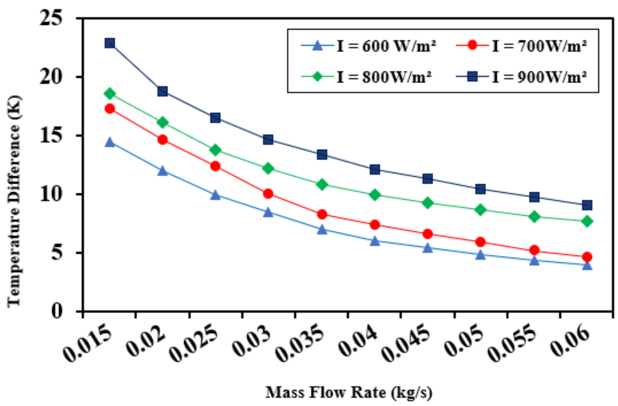


Fig. 6 Temperature differential variation with respect to mass flow rate for various solar radiations (Finned Absorber, Experimental)

Figure 7 compares the thermal efficiencies of two different solar air collector absorbers (a plane absorber and a finned absorber) at solar radiation of 900 W/m^2. Since there is more surface area for heat transfer with the fin than with the plane absorber, air will take longer to flow through the absorber channels despite the fin's higher efficiency. A finned absorber has a maximum increase in thermal efficiency of 1.264 times when compared to a plane absorber.

The finned absorber raises temperatures the most over the range of mass flow rates, as shown in Figure 8. As the mass flow rate rises for a given value of both with and without fins, the temperature rise declines. Including the fins expands the area where heat can be transferred, which raises the temperature. Additionally, Figure 8 shows that at a lower mass flow rate of 0.015 kg/s, a maximum augmentation of 1.243 times in comparison to the plane absorber was discovered. Because the heat transfer coefficient and heat transfer area are at their highest at this mass flow rate.

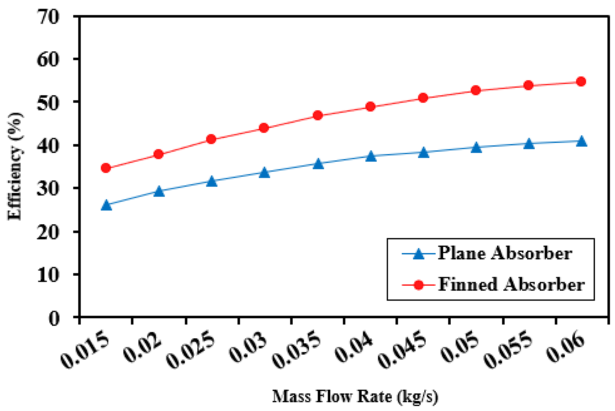


Fig. 7 Comparison of thermal efficiency for plane and finned absorber at solar radiation 900 W/m^2

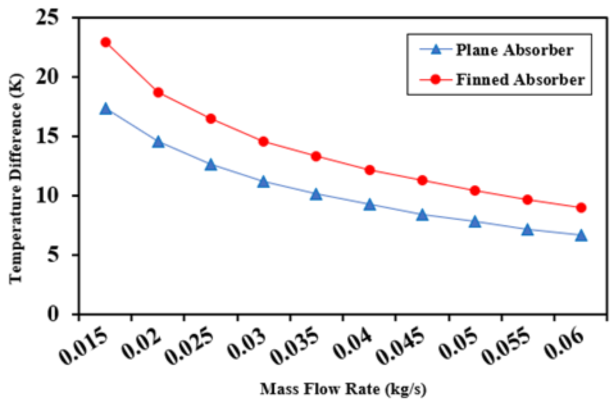


Fig. 8 Comparison between temperature difference for the case (plane and finned absorber) at solar radiation 900 W/m^2

IV. Validation of Work

The thermal efficiency calculated using computational data for rectangular finned and plane absorber solar air heaters has been compared to experimental results. Figure 9 compares the theoretical and experimental thermal efficiency values for identical conditions. Plane absorber and finned absorber collectors are shown to have maximum efficiency deviations of ±4.779% and ±6.144%, respectively. This indicates strong agreement between experimental and theoretical values, ensuring the accuracy of the data gathered through mathematical modeling.

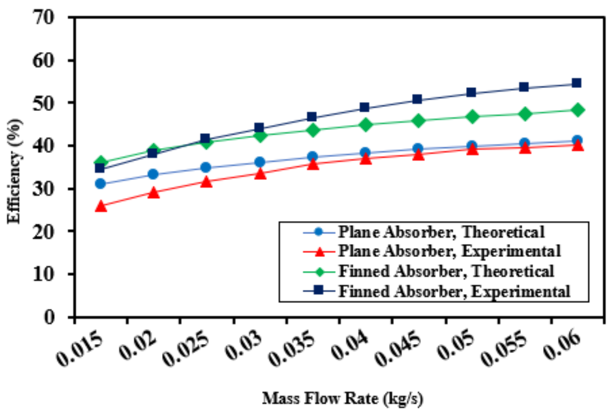


Fig. 9 Comparison of available experimental and theoretical results of thermal efficiency for plane and finned solar air heater at solar radiation 900 W/m^2

V. Conclusions

The following findings can be made after doing an extensive study on a double-pass solar air collector and upgrading the absorber by adding rectangular fins:

- The temperature differential will increase as solar radiation intensity rises.

- The findings indicate that an increase in air mass flow rate has a significant impact on thermal efficiency and heat gain.
- The thermal efficiency of the absorber plate will increase with the addition of fins.
- The finned absorber has a maximum increase in thermal efficiency of 1.264 times when compared to a plane absorber.
- At a lower mass flow rate of 0.015 kg/s, the maximum temperature rise of the finned absorber is 1.243 times in comparison to the plane absorber was discovered.

ACKNOWLEDGMENT

The author conveys sincere gratitude to Dr. San Yu Khaing, pro-rector of Mandalay Technological University. The author would especially like to thank Dr. War War Min Swe, professor, and head of the mechanical engineering department at Mandalay Technological University, for her significant supervision and guidance in completing this study.

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